Chapter 6

SOLID WASTE MANAGEMENT

Overview, Characterization, Processing, and Ultimate Disposal

Dr. Ahmad AbuYaghi Feb. 2022

Land Pollution

- **Land pollution:** involves two man-made activities:

A. Destruction of Earth's surface caused by human activities, including:

1) Acid mine drainage
2) Agrochemicals (Pesticides and herbicides)
3) **Landfills (solid waste disposal).**

B. Misuse of natural resources.

- Natural resources: Land and raw materials that exist naturally in the environment undisturbed by humans.
  - ✓ *Renewable resource*: A natural resource that can be replaced by a natural process (e.g., *groundwater, biomass*).
  - ✓ *Non-renewable resource*: A natural resource that cannot be produced or re-grown or reused (e.g., *oil, natural gas, minerals*).

How do we reduce land pollution?

Definition of Wastes

According to the **Basel Convention**, the definition of Wastes is as follows:

WASTES: "Substances or objects which are

- disposed of , or are
- intended to be disposed of , or are
- required to be disposed of by the provisions of the law".

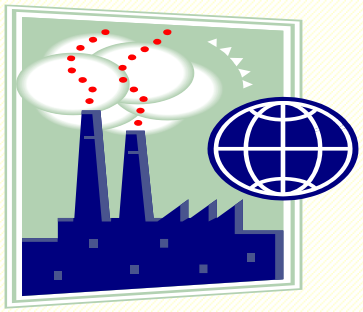
Disposal includes:

"any operation which may lead to resource recovery, recycling, reclamation, direct re-use or alternative uses.

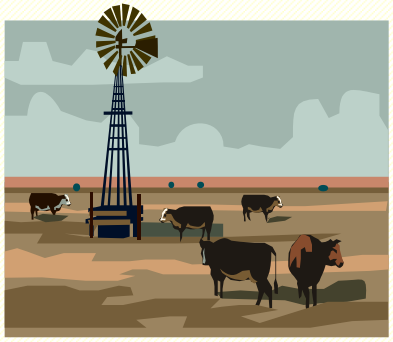
(Annex IVB, Basel convention, Signed March, 1989 and enforced May 1992).

Sources of Solid Wastes

Households



Institutions, Commerce and Industry



Agriculture (both crops and livestock)

Classification of Wastes according to their Effects

- **Hazardous wastes**
- Substances unsafe to use commercially, industrially, agriculturally, or economically and have any of the following properties: ignitability, corrosivity, reactivity & toxicity.
- **Non-hazardous**
- Substances safe to use commercially, industrially, agriculturally, or economically and do not have any of those properties mentioned above. These substances usually create disposal problems.

Classification of Solid Wastes According to their Properties

- **Bio-degradable:**

  can be degraded (paper, wood, fruits and others); produce biogas, fertilizer, etc.

- **Non-biodegradable:**

  cannot be degraded (plastics, bottles, old machines, cans, styrofoam containers and others); *many are recyclable*

AND

- **Combustible:**

  organic (paper, wood, food waste, etc.); recover energy

- **Non-combustible:**

  inorganic (glass, metal and others); recover materials

Solid waste generation rates

Current waste generation per capita by Income Level

Income level	Waste generation per capita (kg/capita/day)		
	Lower boundary	Upper Boundary	Average
High	0.70	14	2.1
Upper Middle	0.11	5.5	1.2
Lower Middle	0.16	5.3	0.79
Lower	0.09	4.3	0.60

Average MSW generation rates by Income Level

Income Level	Average MSW generation (kg/capita/day)
Low income	0.6-1.0
Middle income	0.8-1.5
High income	1.1-4.5

Source: Global Review of Solid Waste Management

Composition of MSW

Proximate Analysis		Ultimate Analysis	
Moisture	16.9 (wt%)	C (carbon)	53.84 (wt%)
Volatile	55.1 (wt%)	H (hydrogen)	5.73 (wt%)
Fixed carbon	8 (wt%)	O (oxygen)	32.93 (wt%)
Ash	20 (%)	N (nitrogen)	1.68 (wt%)
Calorific value	2388 (kcal/kg)	S (sulfur)	0.87 (wt%)

Typical data on the ultimate analysis of the combustile components in residential MSW[a]

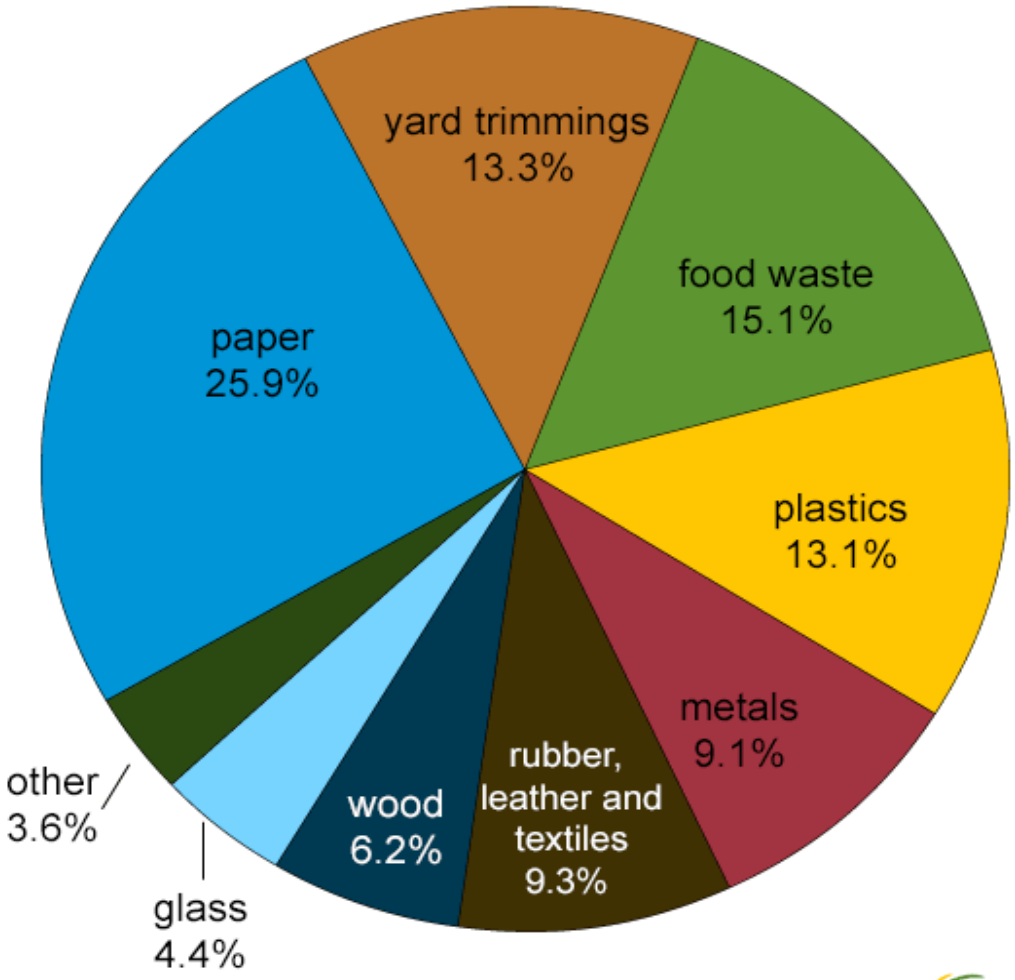
	Percent by weight (dry basis)					
Component	**Carbon**	**Hydrogen**	**Oxygen**	**Nitrogen**	**Sulfur**	**Ash**
Organic						
Food wastes	48.0	6.4	37.6	2.6	0.4	5.0
Paper	43.5	6.0	44.0	0.3	0.2	6.0
Cardboard	44.0	5.9	44.6	0.3	0.2	5.0
Plastics	60.0	7.2	22.8	—	—	10.0
Textiles	55.0	6.6	31.2	4.6	0.15	2.5
Rubber	78.0	10.0	—	2.0	—	10.0
Leather	60.0	8.0	11.6	10.0	0.4	10.0
Yard wastes	47.8	6.0	38.0	3.4	0.3	4.5
Wood	49.5	6.0	42.7	0.2	0.1	1.5
Inorganic						
Glass[b]	0.5	0.1	0.4	<0.1	—	98.9
Metals[b]	4.5	0.6	4.3	<0.1	—	90.5
Dirt, ash, etc.	26.3	3.0	2.0	0.5	0.2	68.0

[a] Adapted in part from Ref. 6.

[b] Organic content is from coatings, labels, and other attached materials.

Total MSW generation in the United States by type of waste, 2015

Total = 262 million tons



Source: U.S. Environmental Protection Agency, Advancing Sustainable Materials Management: 2015 Fact Sheet, July 2018

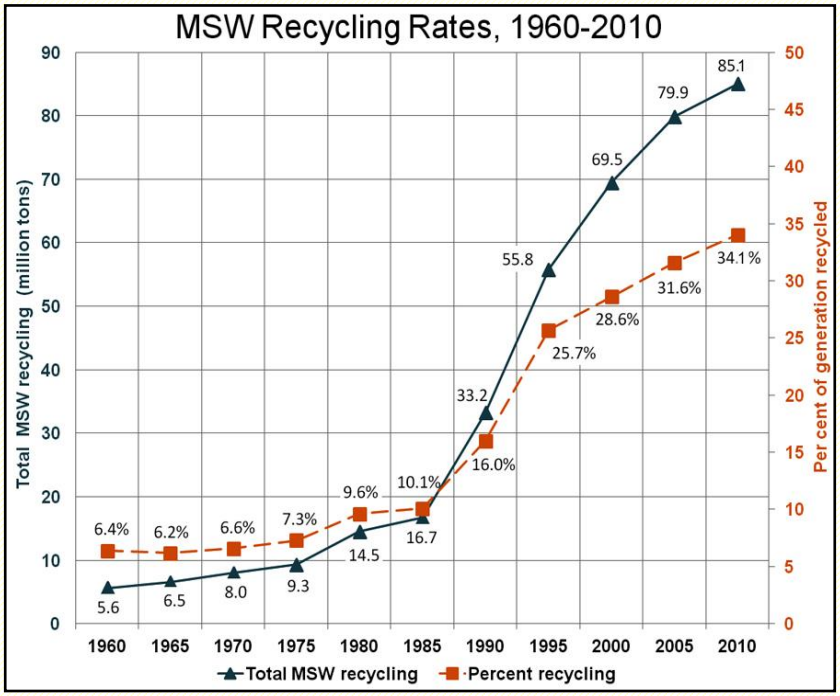
Objectives of SWM

A. The first objective of SWM is to remove discarded materials from inhabited places in a timely manner:

a) to prevent the spread of disease,

b) to minimize the likelihood of fires, and

c) to reduce aesthetic insults arising from putrefying organic matter.

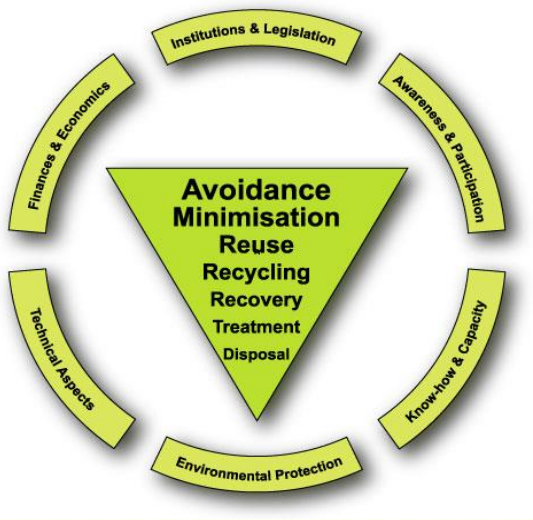


Waste can be a resource

B. The second objective, which is equally important, is to dispose of the discarded materials in a *manner that is environmentally acceptable.*

Sustainability in Solid Waste Management

- Sustainable Waste Management needs to be:
  1. **Environmentally effective**
  2. **Economically affordable**
  3. **Socially acceptable**



- Sustainable solid waste management systems can be engineered by aaccepting the concept of an **"Integrated solid waste management".**

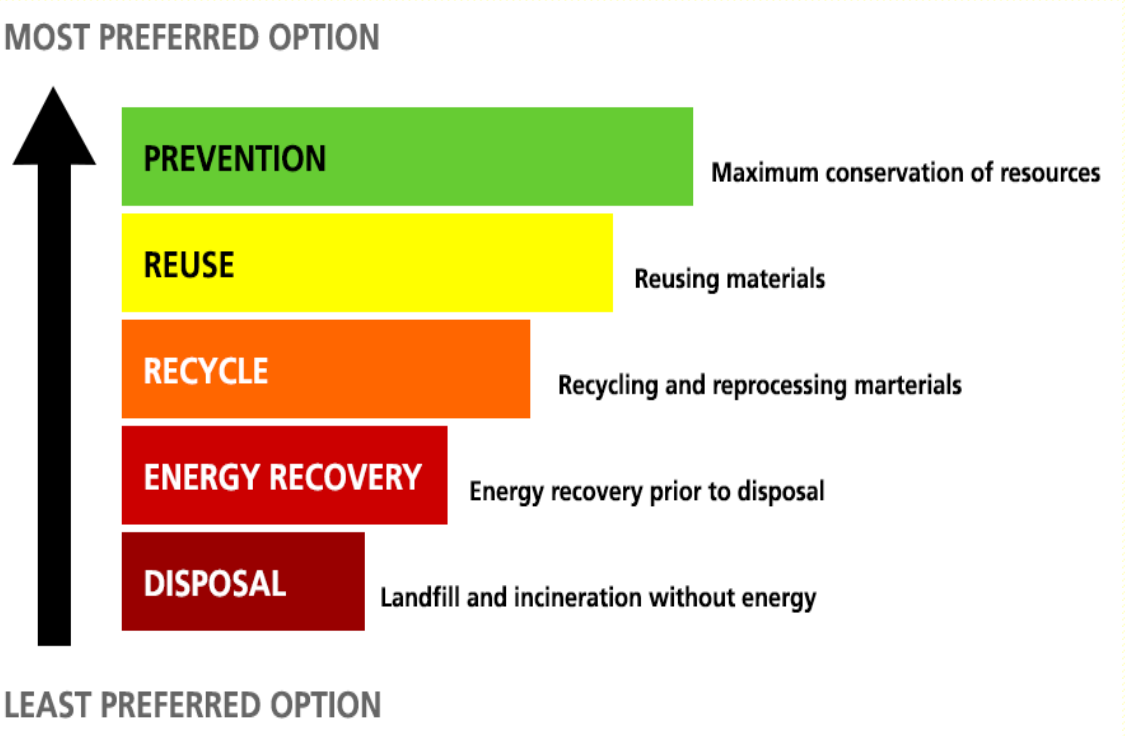
This concept:

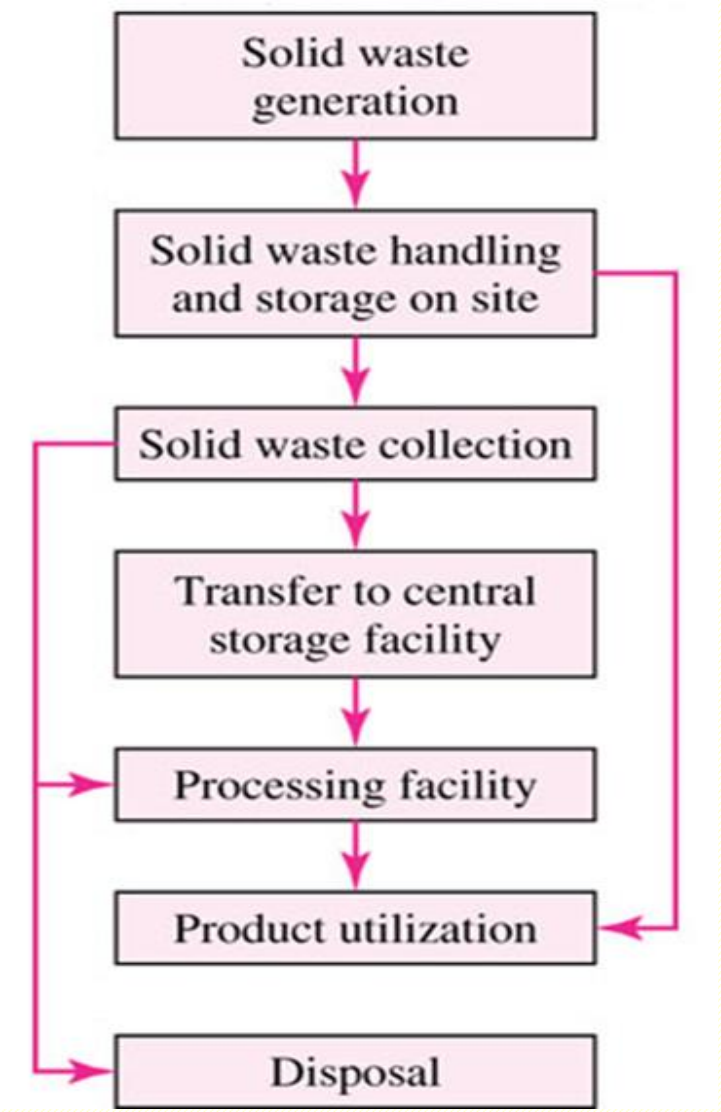
a) takes an overall approach and manages waste in an environmentally effective and economically affordable way;

b) involves the use of a range of different treatment options at a local level; and

c) considers the entire solid waste stream.

Solid Waste Management Hierarchy





Conventional Municipal Solid Waste Management

Modern Trends in Waste Management

- **Zero waste:** Environmentally correct concept is to consider wastes as resources out of place to be used again.
- **Industrial ecology:**
  - Study of relationships among industrial systems and their links to natural systems.
  - Waste from one part of the system would be a resource for another part.
- **Taxation policy:**
  - Countries have moved to cut waste by imposing taxes.
  - Taxation of waste in all its various forms, from emissions from smokestacks to solids delivered to landfills.
  - Rule: As taxes increase, people produce less waste!

Solid waste collection

- **Collection** includes:
  - **a**) temporary storage or containerization,
  - **b**) transfer to a collection vehicle, and
  - **c**) transport to a site where the waste undergoes *processing and ultimate disposal*.
- Waste collection is the *most expensive phase*, largely because it is labor- intensive.

transfer stations often used for processing before transport to landfill

Solid waste processing

Objectives:

1. To save landfill area and volume by reducing total weight and volume of solid waste.
2. To improve and economize the handling and transfer of solid waste by changing its physical form (size, density, moisture content).
3. To recover natural resources in the waste material for reuse or recycling (plastic, metal, glass, paper as well as organic matter as *compost*).
4. To recover energy value from the organic (*combustible*) fraction of solid waste.

Main Steps in solid waste processing

The **most widely used MSW processing** includes:

1. Separation, sorting, classification
2. Shredding and pulverizing
3. Moisture control or dewatering
4. Recycling
5. Composting
6. Incineration

Separation & Shredding

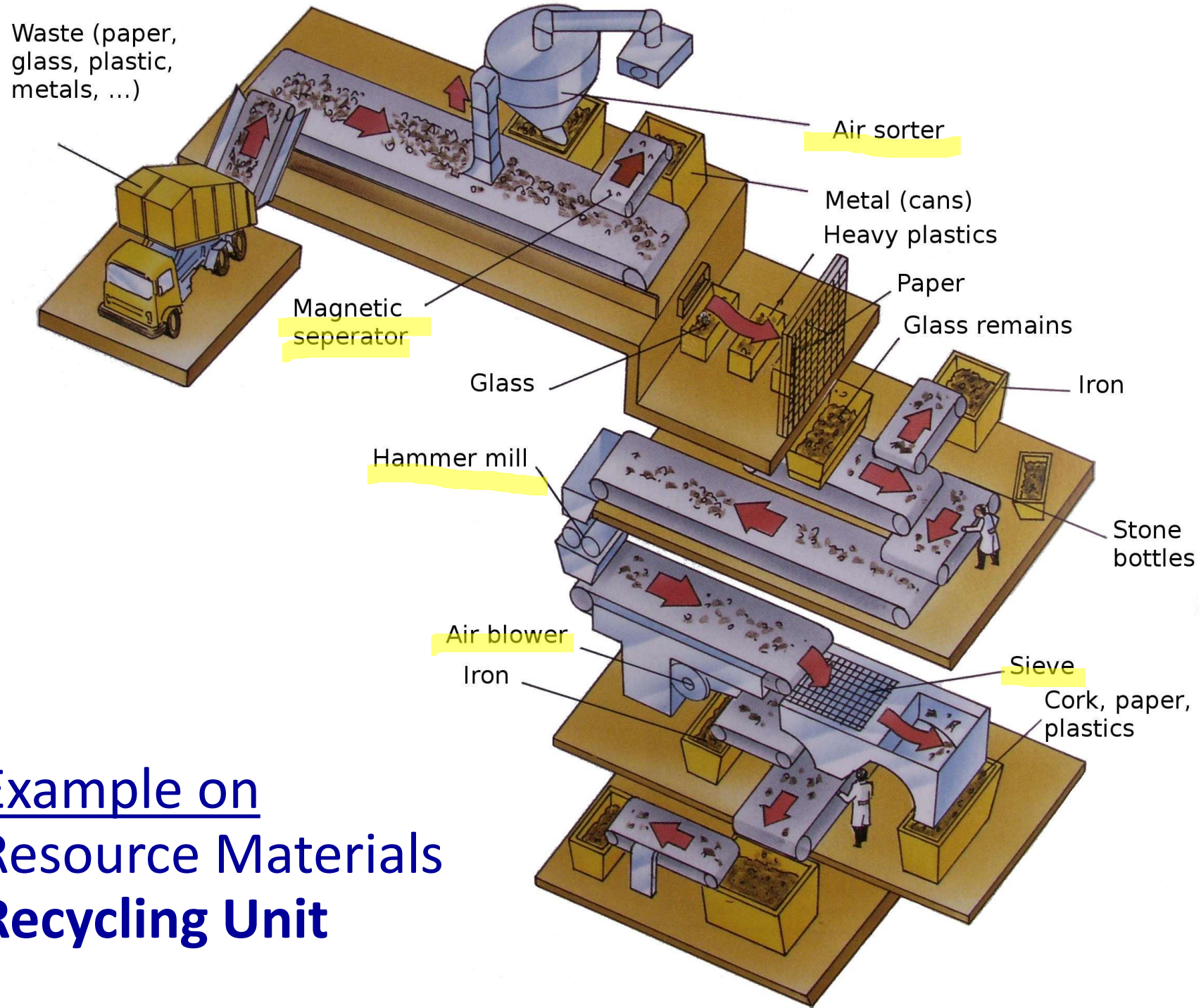
- The first step in a *landfill volume enhancement program*, some materials may be reclaimed at a central processing point.
- The most likely candidates for recycling are *paper and ferrous metals.*
  - ❖ Paper generally is removed by hand as the MSW passes along on a conveyor belt.
  - ❖ After passing through a shredder, ferrous metals can be removed using a magnetic separator.
- Asphaltic concrete plants may be able to use the *shredded tires* in their raw material feedstock.

Recycling

- Is the reprocessing of wastes to recover an original raw material.
  - At its lowest and most appropriate technological level, the materials are ***separated at the source*** by the consumer.
  - This is the most appropriate level because it requires the minimum expenditure of energy.
- Generally, the recycling options available to a municipality for residential use include:
  1. **Curbside collection**
  2. **Drop-off centers**
  3. **Material transfer stations**
  4. **Material processing facility**

2017 Curbside Collection Schedule

Material	Week 1	Week 2	Week 3	Week 4
Organics	✓	✓	✓	✓
Recycling	✓	✓	✓	✓
Residual Garbage		✓		✓

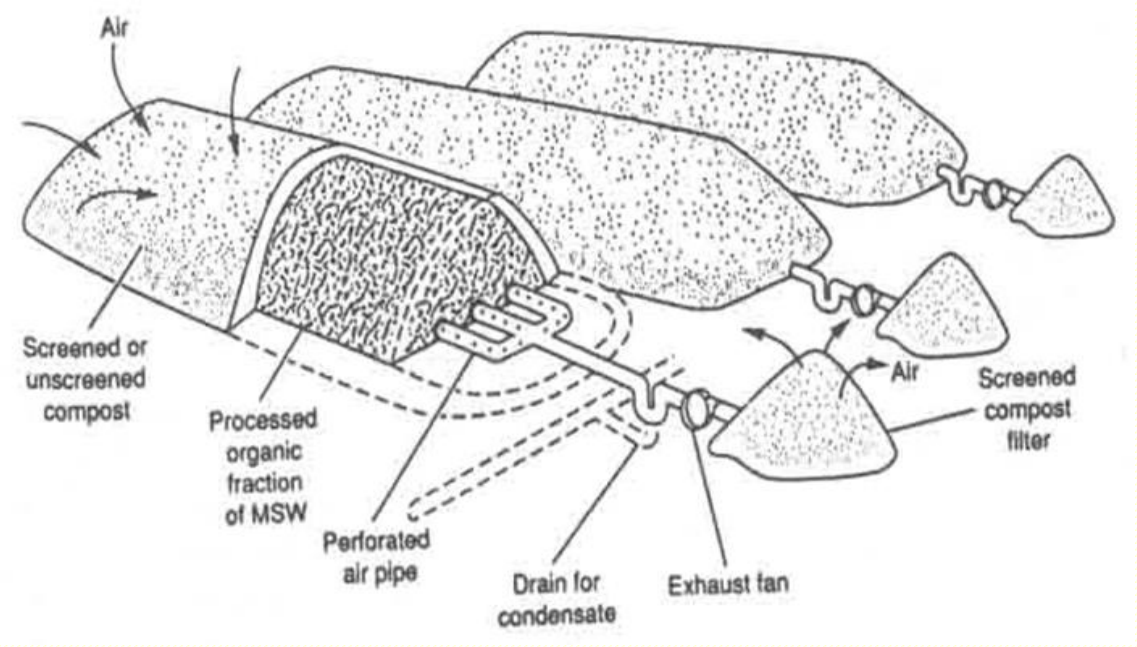


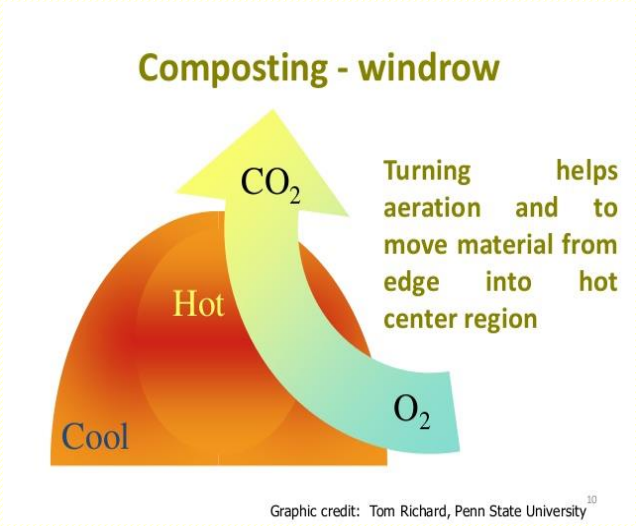
Example on Resource Materials **Recycling Unit**

Composting

- Composting is a process in which the organic portion of MSW is allowed to decompose under carefully controlled conditions by the action of bacteria, fungi and other microorganisms.
- With proper control of moisture, temperature and aeration, a composting plant can reduce the volume of the raw organic material by as much as 50 percent.
- A complete **MSW composting operation** includes:
  - sorting and separating,
  - shredding and pulverizing,
  - digestion,
  - product upgrading and marketing.
- The composting waste is aerated by periodically turning each windrow.
  - This can be done **manually with a pitchfork**, but at most large facilities it is **machinery.**
  - Some of these machines turn and rebuild the windrow directly behind the machine; others rebuild the turned windrow adjacent to its original position (see Figure).

Composting





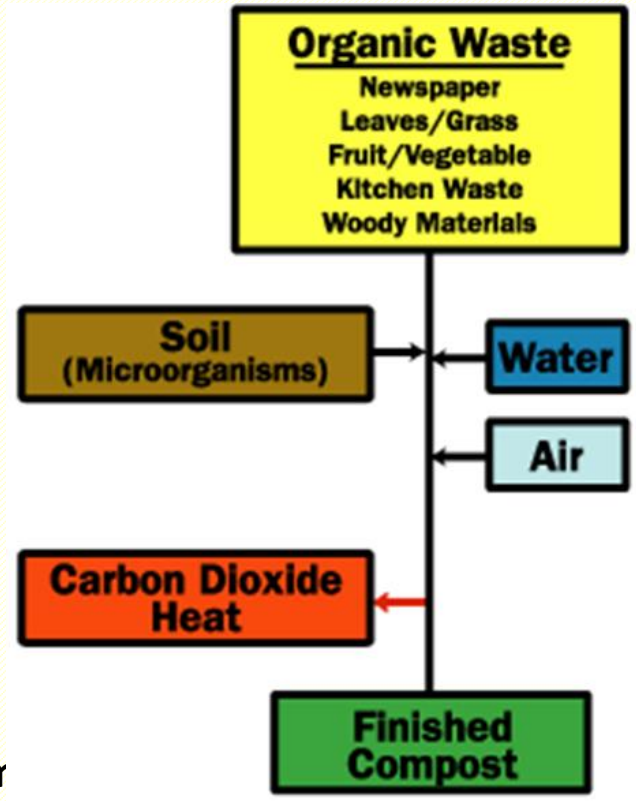


Figure 8. Schematic of aerated static pile composting system

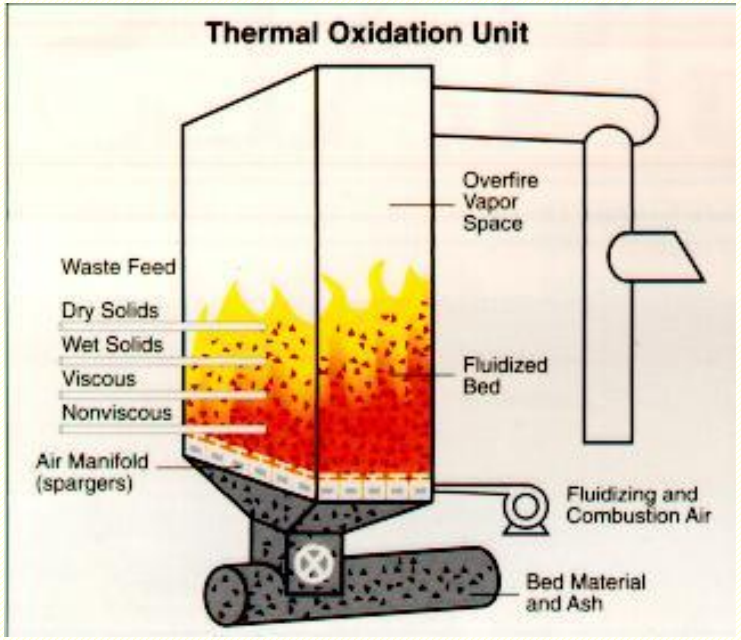
Composting

- Product is "Compost", which is a humus-like material that results from the aerobic biological stabilization of the organic materials in solid waste.
- Compost is useful as a soil conditioner. In this role compost will:
  1) improve soil structure,
  2) increase moisture-holding capacity,
  3) reduce leaching of soluble nitrogen, and
  4) increase the buffer capacity of the soil.

- Compost also has a value as plant fertilizer. It contains a small percentage of major nutrients, such as *nitrogen, phosphorus, and potash.*

INCINERATION: W2E Combustion

1. **Incineration** is a thermal oxidation with the furnace temperatures are about 815-1400 ^{0}C.
2. **Incineration results** in products of complete or incomplete combustion): CO_2, H_2O, CO, hydrocarbon, other organic matter, NOx
3. **Operation of incinerator:**
   a) Good understanding of waste characteristics
   b) Technical skills of operator
   c) Control of waste feed
   d) Mixing of wastes
   e) Constant Temperature
   f) Excess air
   g) Flue gas control
   h) Regular maintenance



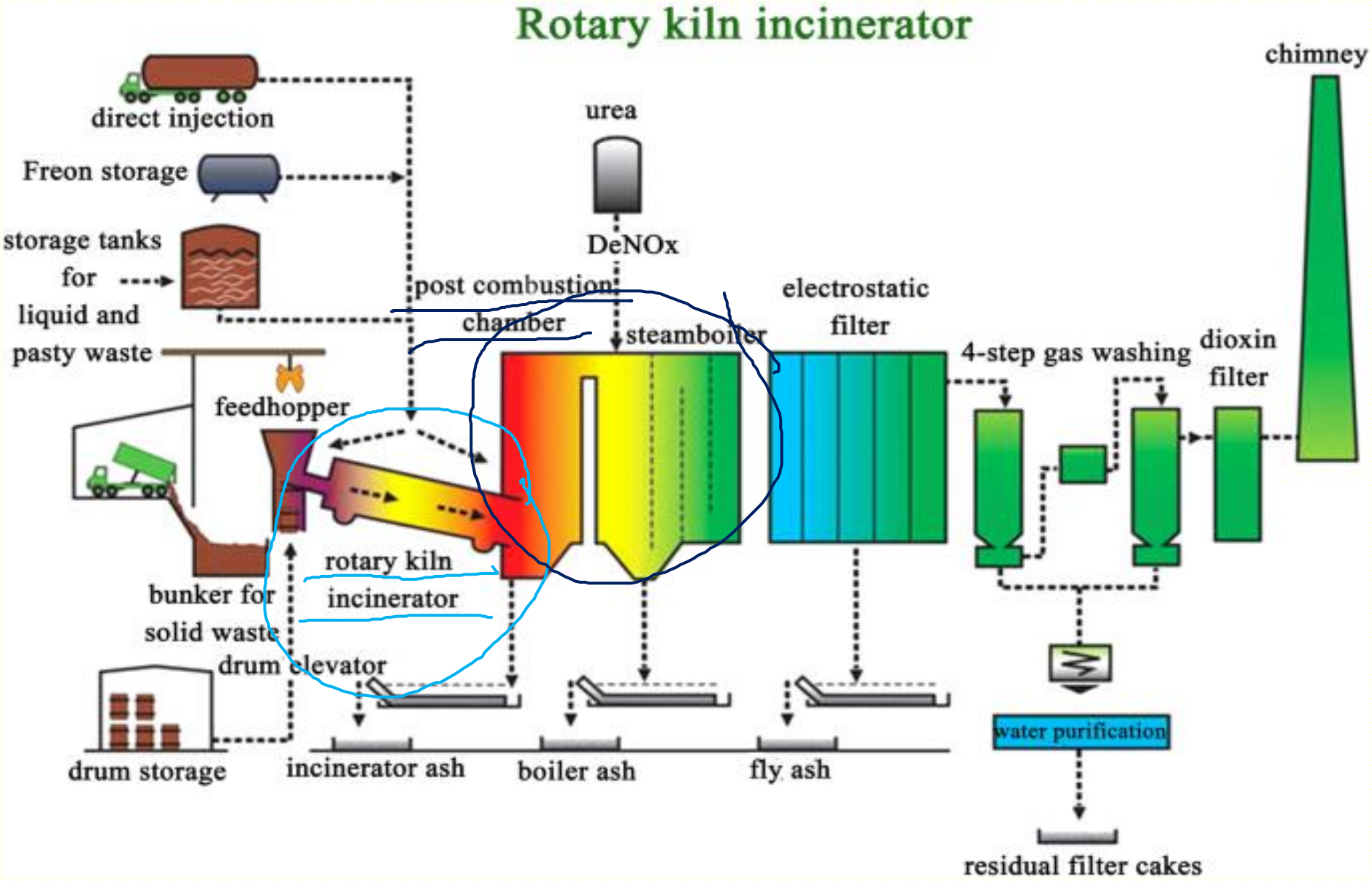
INCINERATION: W2E Combustion

- For MSW, the following **types of incinerators** can be used:
  1) Rotary kiln incinerator
  2) Fluidized bed incinerator
  3) Refuse-derived fuel facility

- Incineration has been used to reduce the bulk of the solid waste:
  a) Where land is no longer abundant or
  b) where geotechnical and environmental considerations would limit the use of a sanitary landfill.
- Although the solid waste may have some heat value, it is normally *quite wet and is not self-sustaining in combustion until it is dried.*
- Conventionally, auxiliary fuel is provided for the initial drying stages.

- The basic arrangement of the conventional incinerator is shown in *Figure (Next).*

Rotary kiln incinerator



Energy Recovery from MSW

TABLE 8-12
Net heating value of various materials

Material	Net heating value (MJ/kg)
Charcoal	26.3
Coal, anthracite	25.8
Coal, bituminous (hi volatile B)	28.5
Fuel oil, no. 2 (home heating)	45.5
Fuel oil, no. 6 (bunker C)	42.5
Garbage	4.2
Gasoline (regular, 84 octane)	48.1
Methane[a]	55.5
Municipal solid waste (MSW)	10.5
Natural gas[a]	53.0
Newsprint	18.6
Refuse derived fuel (RDF)	18.3
Rubber	25.6
Sewage gas[a]	21.3 to 26.6
Sewage sludge (dry solids)	23.3
Trash	19.8
Wood, oak	13.3 to 19.3
Wood, pine	14.9 to 22.3

[a] Densities taken as follows (all in kg/m^3): CH_4 = 0.680; natural gas = 0.756; sewage gas = 1.05

INCINERATION

✓ **Dulong Equation:**

Gross Calorific Value *W: weight %*

$= 8140 * W_C + 34400 * (W_H - W_O/8) - 0.12 * W_N + 2220 * W_S$

(kCal/Kg)

OR:

$$\frac{KJ}{kg} = 337C + 1428\left(H - \frac{O}{8}\right) + 9S$$

C, H, O, S: weight %

❑ Because the large amount of *particulate matter* generated in the combustion process,

- *Some type of air pollution control device is required.*
- *Normally, electrostatic precipitators (ESP) are chosen.*

❑ Bulk volume reduction in incinerators is about 90 percent.

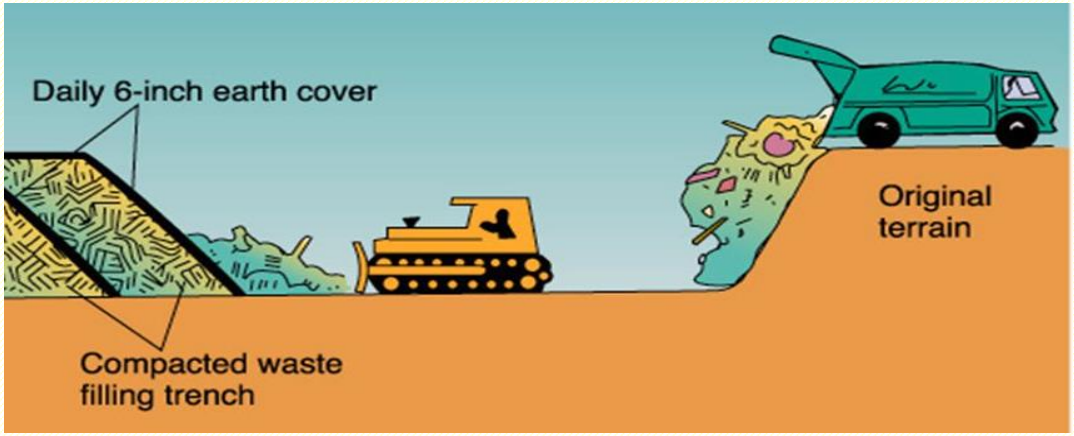
- Thus, about 10 percent of the material (ash) still *must be carried to **landfill.***

DISPOSAL BY SANITARY LANDFILL

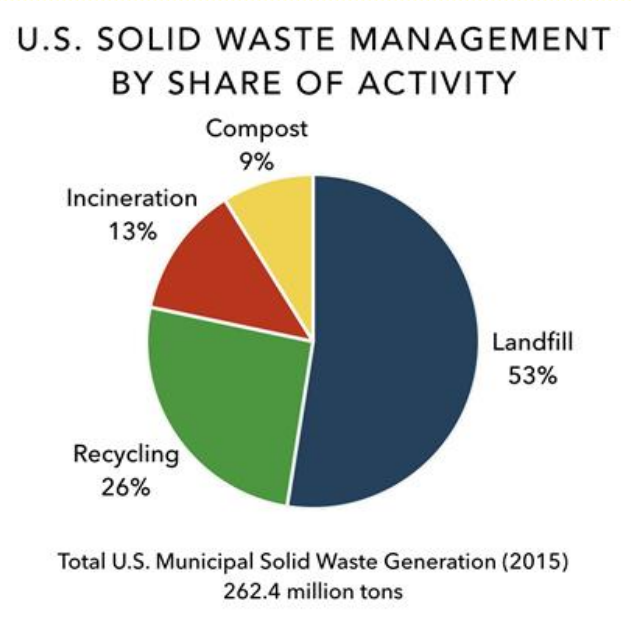
1) Definition and importance
2) Landfill site selection
3) Site preparation
4) Landfill design & operations
5) Environmental (Health & Pollution) Considerations
6) Landfilling in Jordan

DISPOSAL BY SANITARY LANDFILL

- The **sanitary landfill** is defined as a land disposal site employing an engineered method of disposing of solid wastes on land in a manner that minimizes environmental hazards.
- This is achieved by:
  - spreading the solid wastes to the smallest practical volume, and
  - applying & compacting *cover material* at the end of each day.
- Landfill is the most abundant and ultimate solution of solid waste disposal:

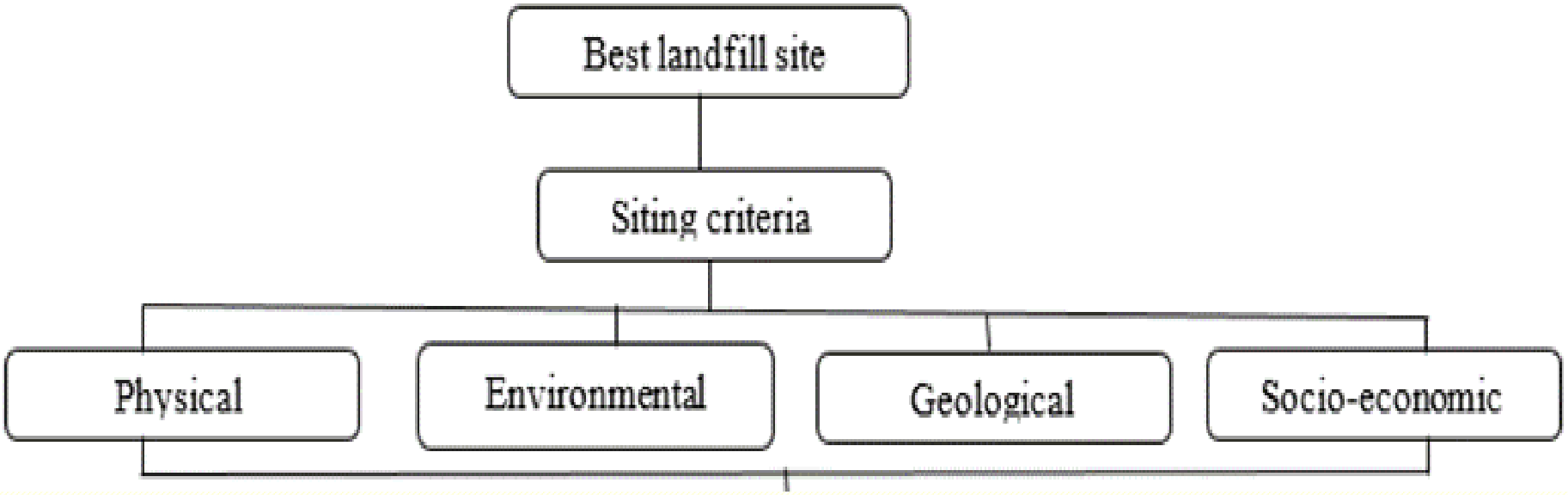


DISPOSAL BY SANITARY LANDFILL



Site Selection Criteria and Factors

- Site location is perhaps the most difficult obstacle to overcome in the development of a sanitary landfill.
- Opposition by local citizens eliminates many potential sites / they are consulted during scoping session in the preparation of EIA study.
- In choosing a location for a landfill, consideration should be given to *the factors below.*



Site Selection Criteria and Factors

1) Hydrology
2) Climate (floods, snow)
3) Availability of cover material
4) Proximity of major roadways
5) Haul distance (in time)
6) Bridge capacities
7) Traffic patterns and congestion
8) Buffer areas around the site (for example, high trees on the site perimeter)
9) Historic buildings, endangered species, wetlands, and similar environmental factors.

Site Preparation

1. Plans: maps and specifications.
2. Operations: grading the site area, constructing access roads and fences, and installing signs, utilities & operating facilities.
3. On-site access roads should be of all-weather construction and wide enough to permit two-way truck travel.
4. All sanitary landfill sites should have utilities: electric, water, and sanitary services.
5. Water should be available for drinking, fire-fighting, dust control, and sanitation.

Landfilling Equipment

- A wide variety of equipment is available from which to select the proper type and size needed for an efficient operation.
- The size and type of equipment required at a sanitary landfill *depends on*:

  - size and method of operation,
  - quantities of solid waste deliveries, and
  - experience and preference of designer and equipment operators.
  - availability and dependability of service from the equipment.

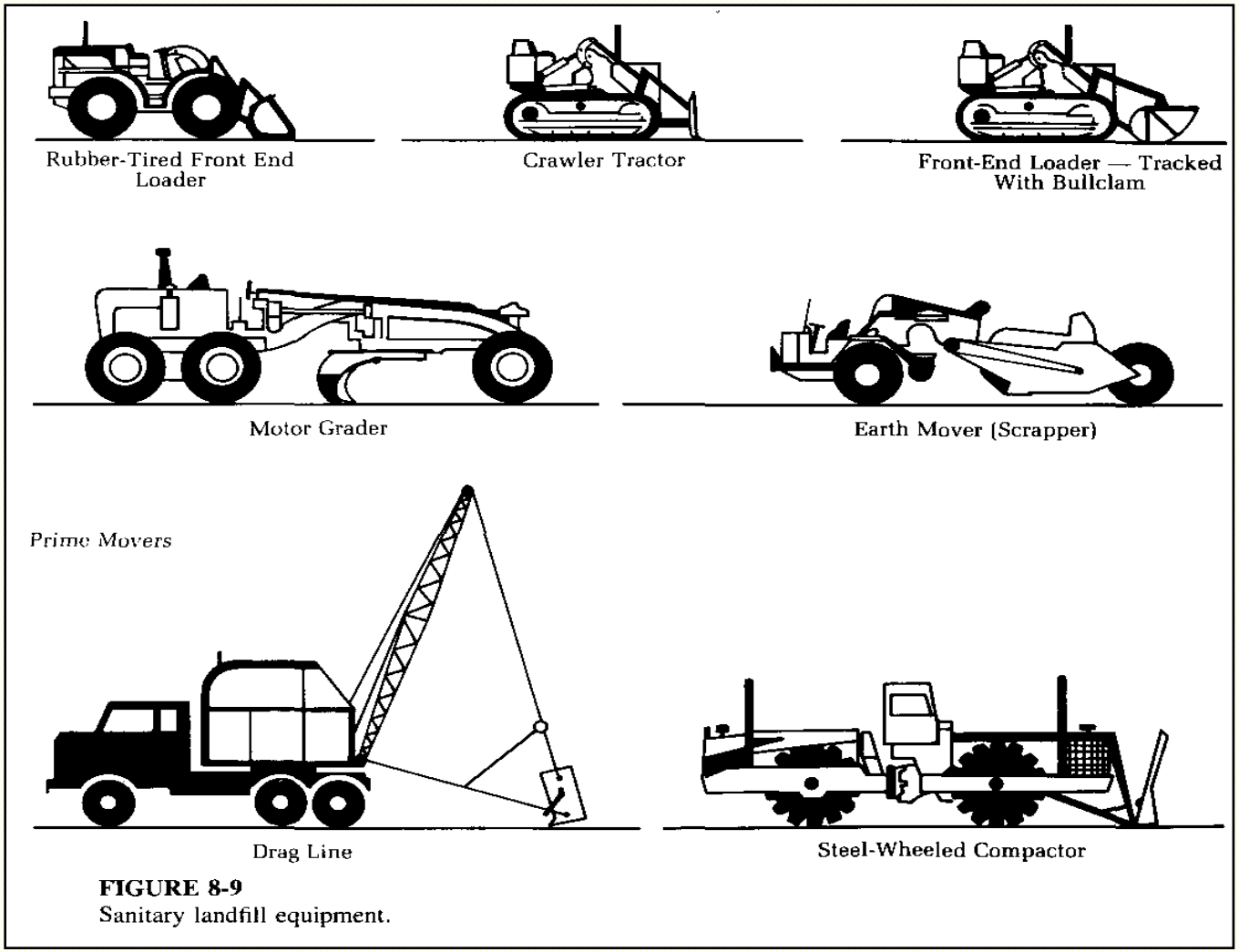


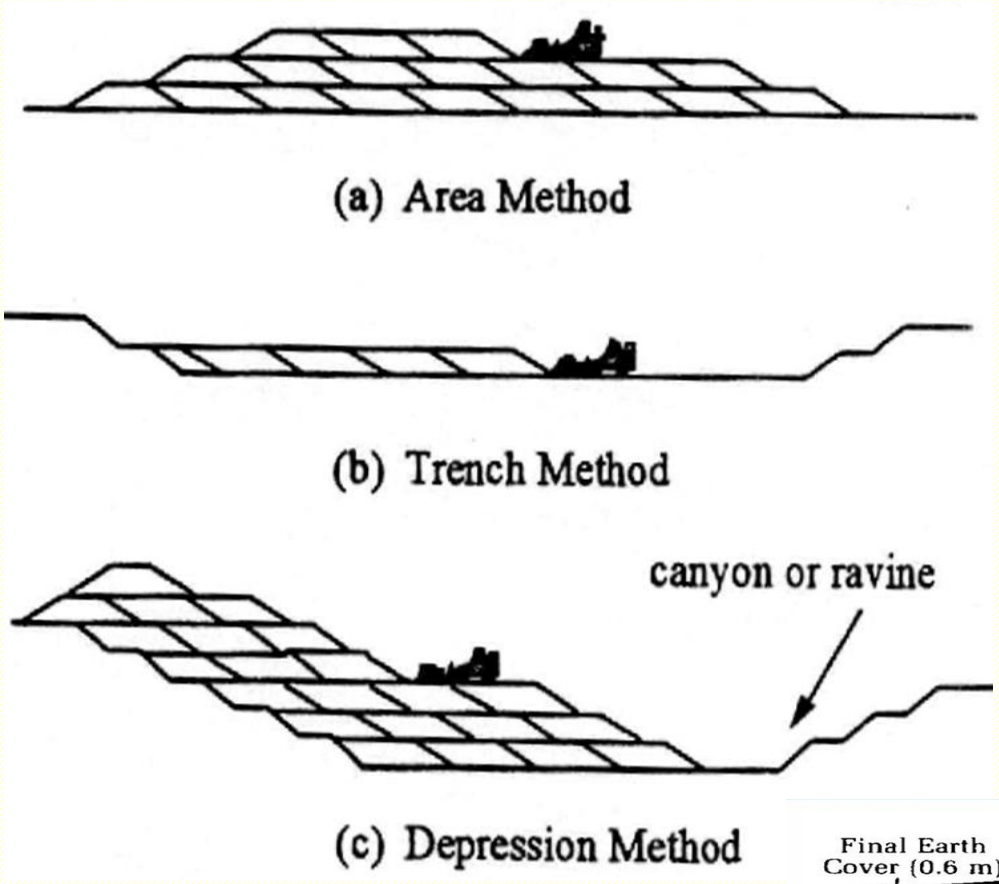
FIGURE 8-9
Sanitary landfill equipment.

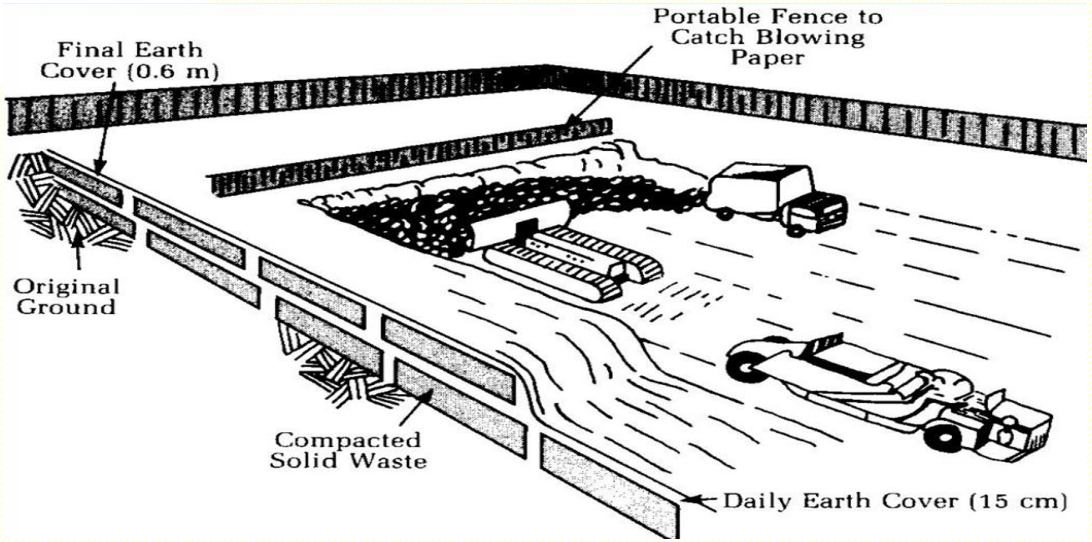
Landfilling Equipment

- The most common equipment used on sanitary landfills is the *crawler or rubber-tired tractor*
- The tractor can be used with a dozer blade, trash blade, or a front-end loader.

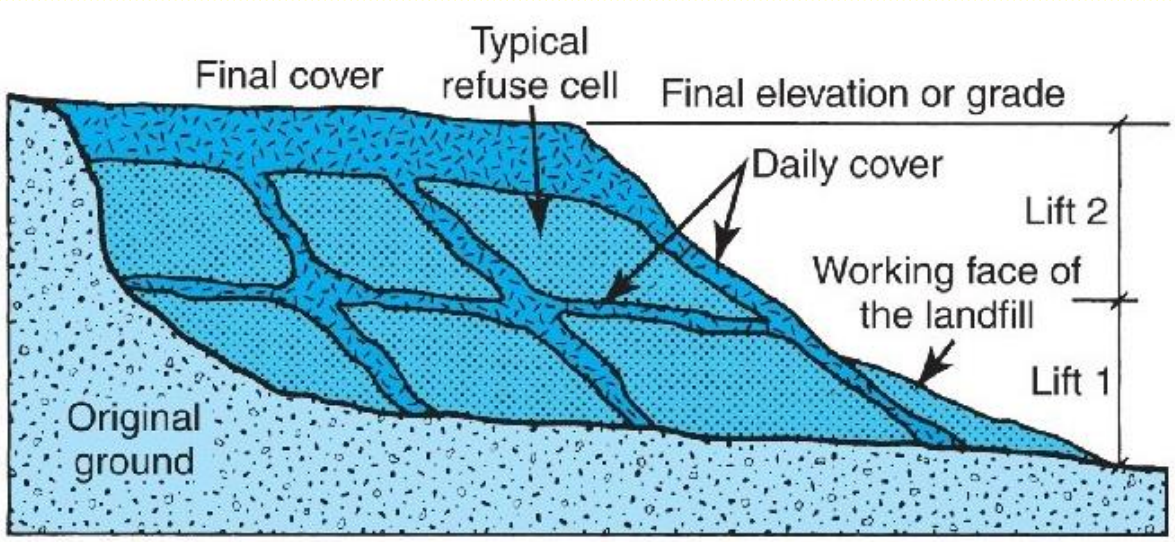
1) A tractor is versatile and can perform a variety of operations:
   - *spreading, compacting, covering, trenching, and even hauling the cover material.*
2) The decision on whether to select *a rubber-tired or a crawler-type tractor and a dozer blade, trash blade, or front-end loader* must be based on the conditions at each individual site.

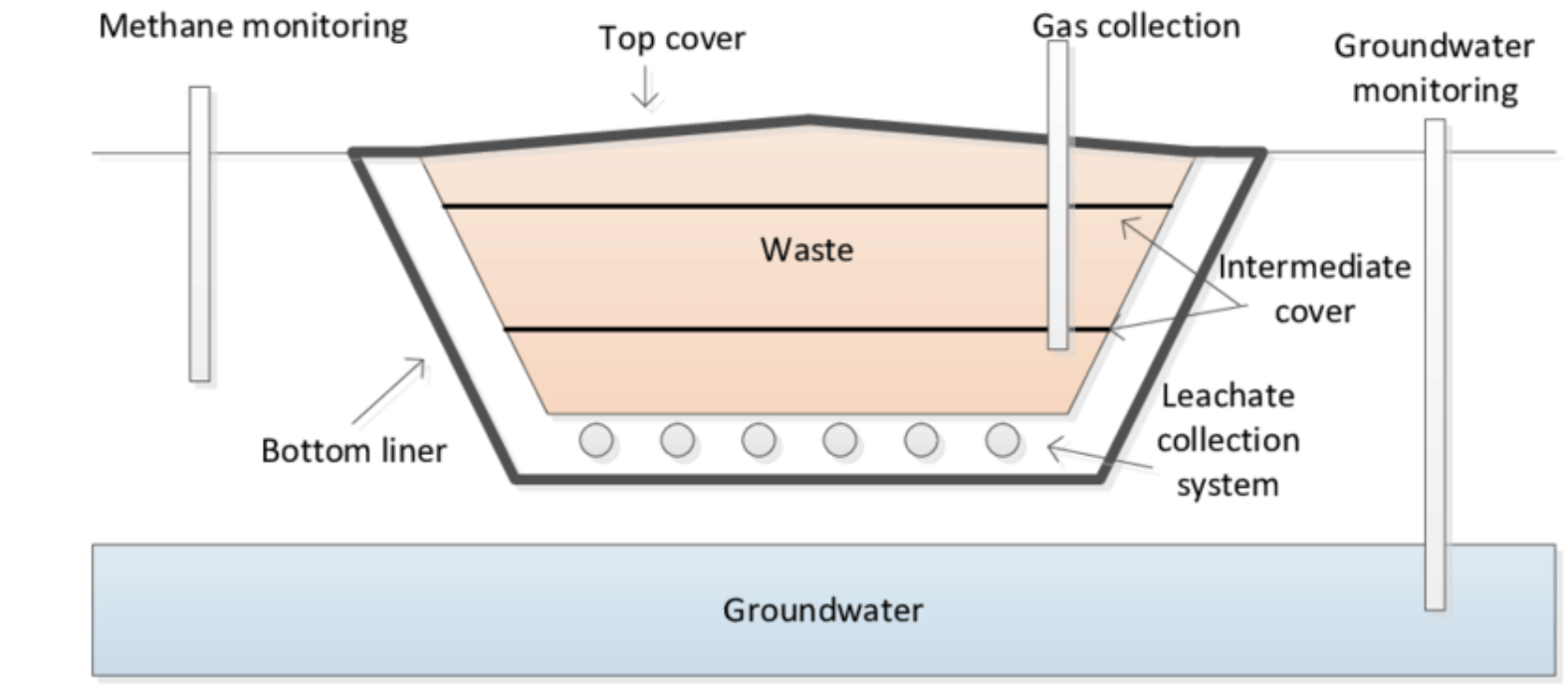
Landfilling Methods





SANITARY LANDFILL





Environmental Considerations

1) Vectors (carriers of disease),
2) Air and Water pollution, should not be problems in a properly designed, operated and maintained landfill.

- Important factors in achieving insect, rodents and fire control:

a) well-compacted solid wastes
b) well-compacted cover material (soil)
c) good housekeeping, and
d) timely (daily) covering of the solid waste.

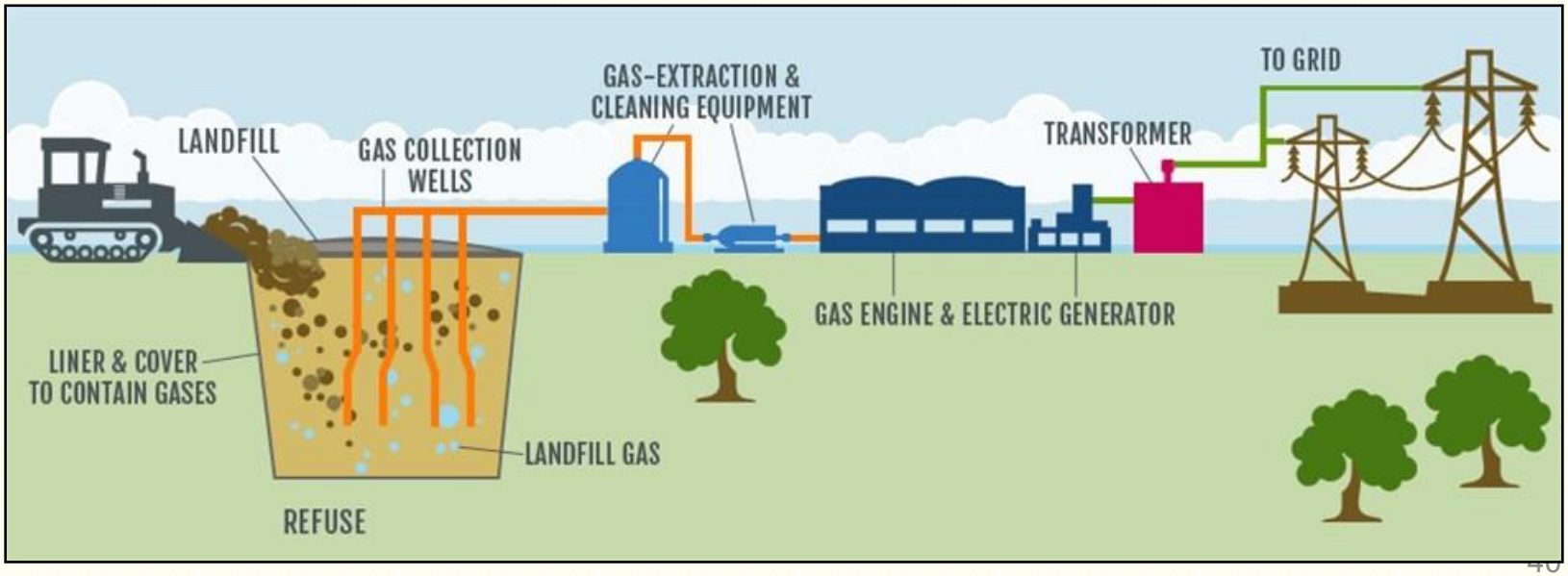
Environmental Considerations

Important factors in air pollution control:

1) Burning is never permitted at a sanitary landfill.
2) Accidental fires should be extinguished immediately using soil, water or suitable chemicals.
3) Odors can be controlled by:
   - covering the wastes quickly and carefully, and by
   - *sealing any cracks* that may develop in the cover.
4) Biogas control *(leak-proof collection, storage and use).*

Environmental Considerations: BIOGAS

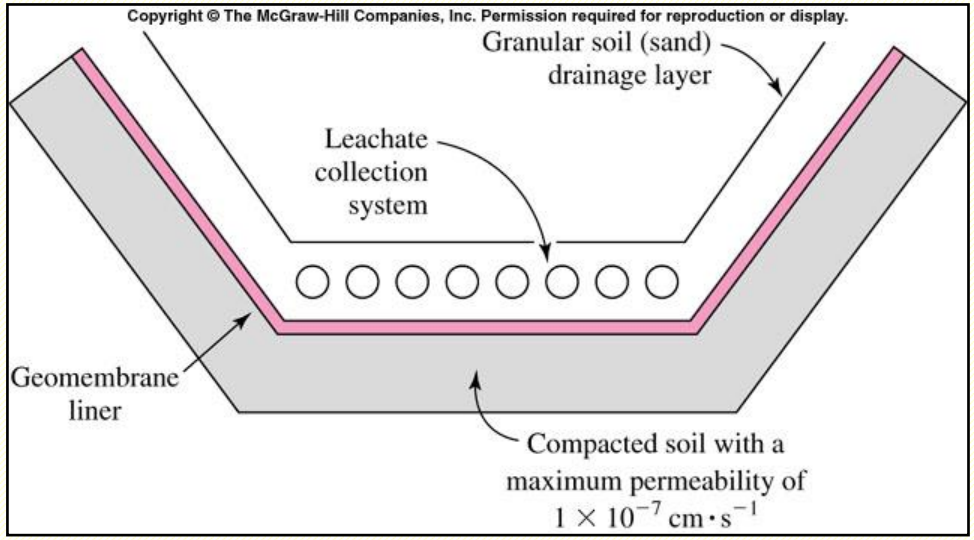
- Principal gaseous products resulting from bacterial decomposition of waste are methane, nitrogen, carbon dioxide, hydrogen, and hydrogen sulfide.
- Studies indicate that during *early years* of landfill life, the predominating gas is carbon dioxide, while during *later years* the gas is composed almost equally of carbon dioxide and methane.
- Because methane is explosive, its movement must be controlled.
- Some landfills have been tapped with wells to collect the methane for local and commercial use as an energy source.



Leachate & its Control

Leachate:

Water that passes through the landfill carrying extracted dissolved and suspended matter.



1. Solid wastes placed in a sanitary landfill may undergo a number of biological, chemical & physical changes.
2. Aerobic and anaerobic decomposition of the organic matter results in *both gaseous & liquid end products*.
   - ❑ Some materials are chemically oxidized.
   - ❑ Some solids are dissolved in water percolating through the landfill.
3. Because of the differential heads (slope of the surface), the water containing those dissolved substances moves into the groundwater system.
4. The result is gross pollution of the groundwater.

Leachate & its Control

- Some of the stricter requirements for landfill leachate control include ***several layers*** to catch the leachate.
- From top to bottom the layers are:
  1. under-drain pipes
  2. plastic liner
  3. second layer of under-drain pipes (in case the first liner leaks)
  4. second plastic liner
  5. impermeable clay

- Proper planning, site selection, and operating normally can *minimize* the possibility of surface and groundwater pollution.
- Some common preventive measures are

a) Locating the site at a *safe distance* from streams, lakes & wells.

b) Avoiding site locations above porous soil.

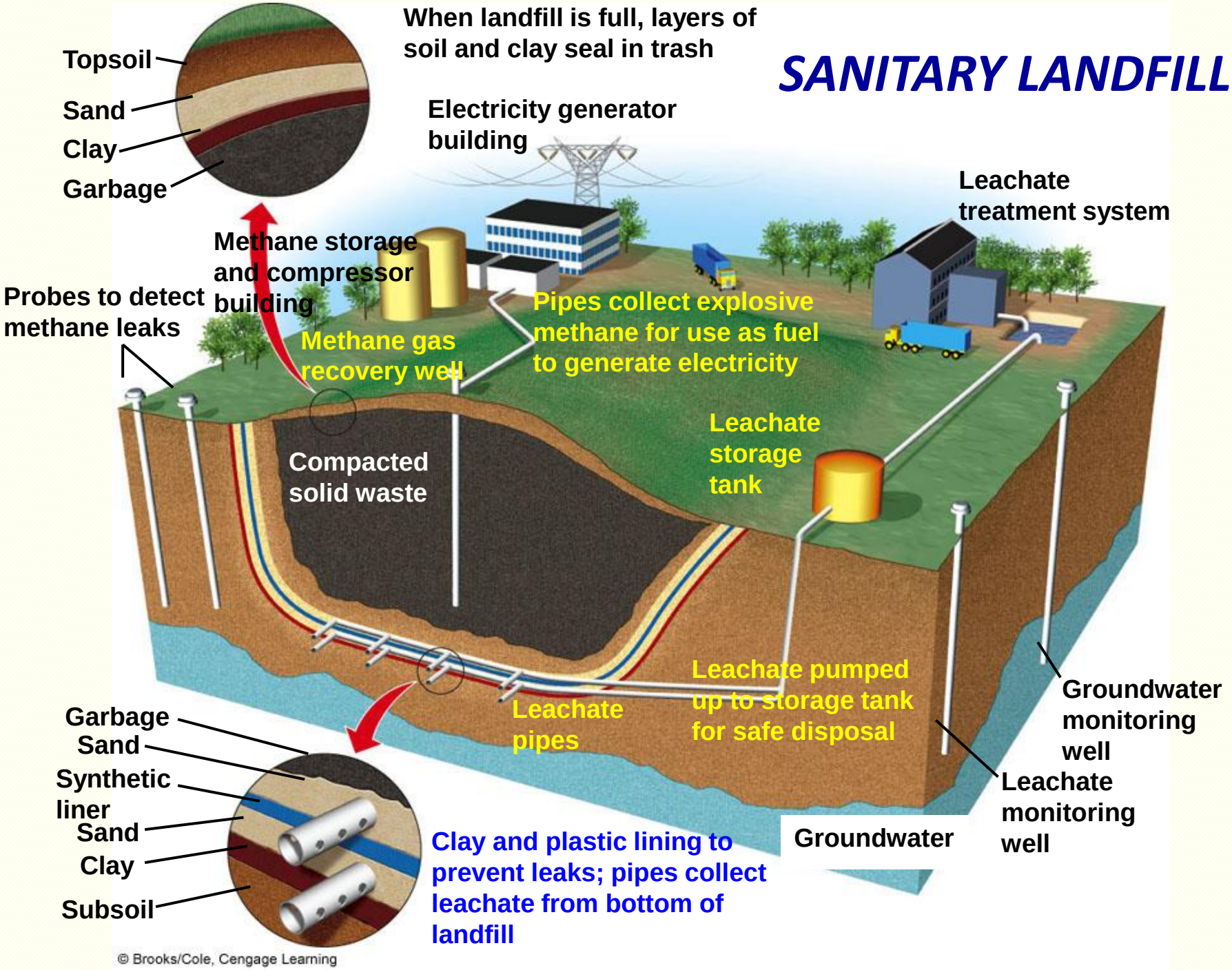
c) Using an earth cover (soil) that is nearly impervious.

d) Providing suitable drainage.

Leachate Composition

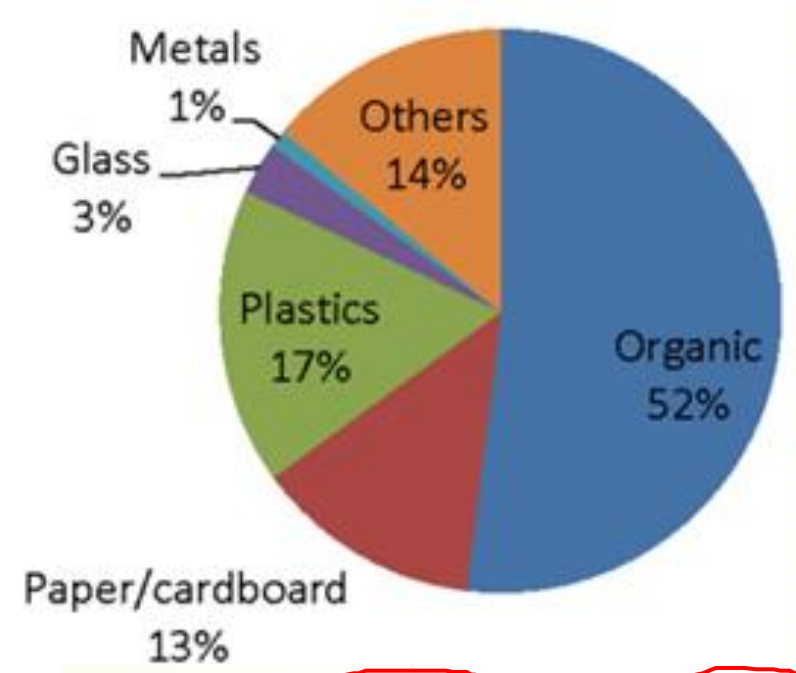
Parameter	Typical Range (milligrams per liter, unless otherwise noted)	Upper Limit (milligrams per liter, unless otherwise noted)
Total Alkalinity (as $CaCO_3$)	730–15,050	20,850
Calcium	240–2,330	4,080
Chloride	47–2,400	11,375
Magnesium	4–780	1,400
Sodium	85–3,800	7,700
Sulfate	20–730	1,826
Specific Conductance	2,000–8,000 µmhos cm^{-1}	9,000 µmhos cm^{-1}
TDS	1,000–20,000	55,000
COD	100–51,000	99,000
BOD	1,000–30,300	195,000
Iron	0.1–1,700	5,500
Total Nitrogen	2.6–945	1,416
Potassium	28–1,700	3,770
Chromium	0.5–1.0	5.6
Manganese	Below detection level – 400	1,400
Copper	0.1–9.0	9.9
Lead	Below detection level – 1.0	14.2
Nickel	0.1–1.0	7.5

SANITARY LANDFILL



SWM in Jordan

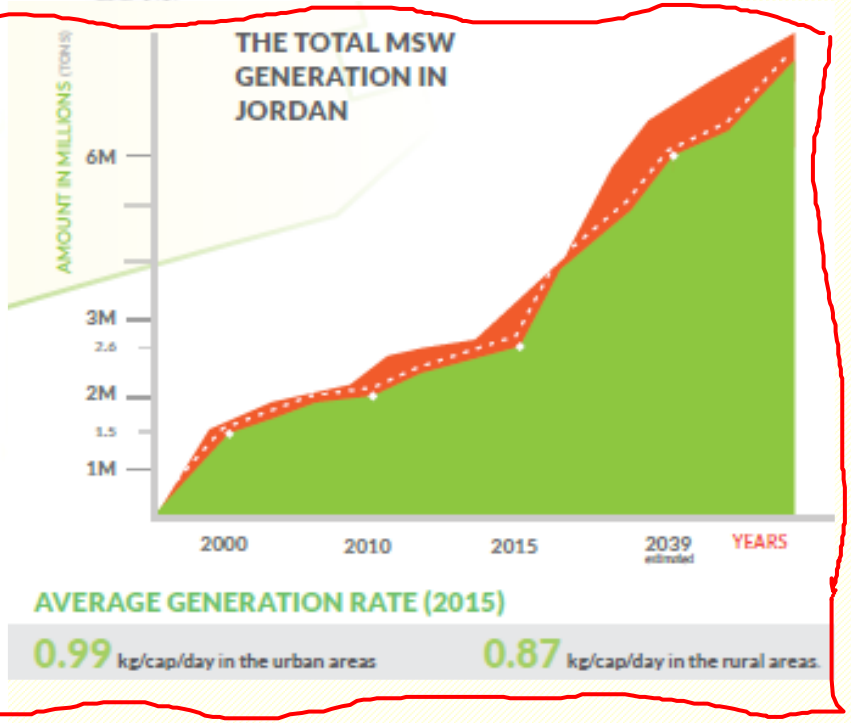
Constituents of Municipal Solid Waste (MSW) in Jordan:



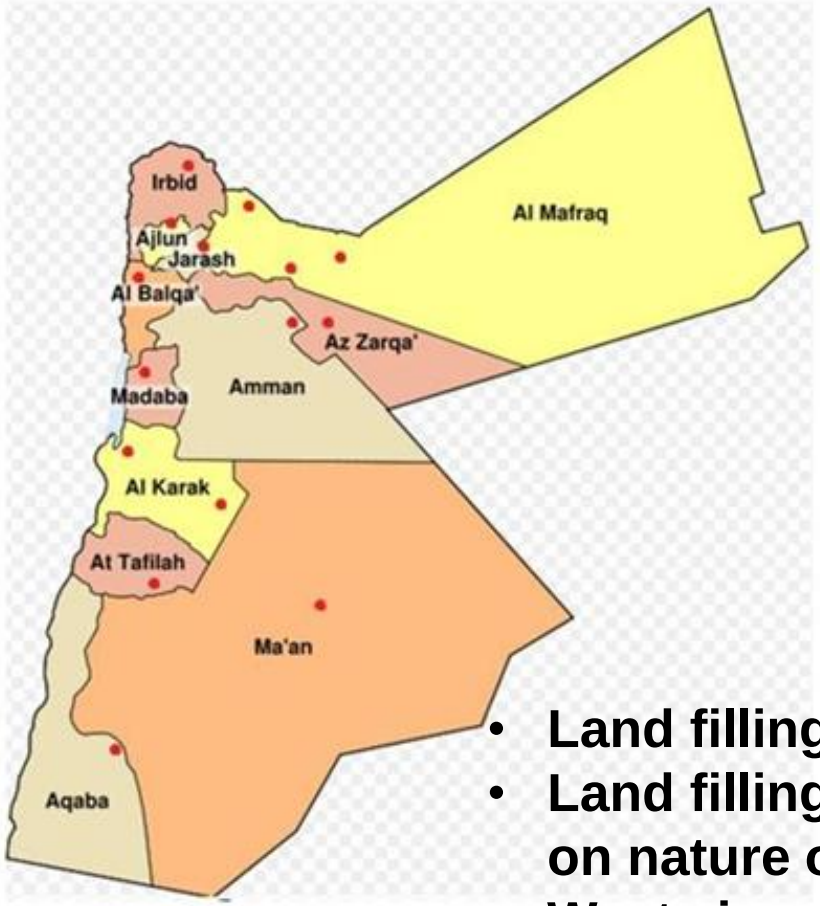
MSW Technical Performance

MSW Collection Coverage	
In rural area	70 %
In urban area	90%
Composition of MSW by Generator (%)	
Domestic and commercial	80%
Industrial	20%
Management of Waste (%) MSW Final destination	
Composted	0%
Recycled	10%
Disposed in engineered landfills	50%
Disposed in controlled dumps	35%
Disposed in open dumps	5%

The daily estimated solid waste generated in 2011 was about 5,846 tons



Solid Waste Responsibilities in Jordan



12 governorates

93 municipalities

collection and transportation

22 Common Service Councils(CSCs)

Operation and management Landfills

24 Landfill

- **Land filling using trench method**
- **Land filling using cell method is used depending on nature of the site**
- **Waste is spread in layers and compacted by heavy machinery to reduce its volume then covered by daily and final soil cover**
- **No lining , leachate and biogas collection, except for Al-Ghabawi landfill near Amman.**

REFERENCES

1. Peavy, H.S.; D.R. Rowe and G. Tchobanoglous. Environmental Engineering, McGraw-Hill, 1985.
2. George Tchobanoglous and Frank Kreith. Handbook of Solid Waste Management, Second Edition, McGraw-Hill, 2nd Edtion, 2002.
3. Cheremisinoff. Handbook of Solid Waste Management and Waste Minimization Technologies, 2005.
4. P.A.Vesilind, W.Worrell & Debra Reinhart. Solid Waste Engineering, 2002.